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**SENSITIVITY EVALUATION OF
M15 AND ANALOG MINES**

**LAWRENCE J. VANDE KIEFT
DENNIS L. BOWMAN**

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| 13. ABSTRACT (Maximum 200 words) <p>Land mines are a very serious threat to Army operations. <i>This study analyzes the task of which this study was a part</i> involves the explosive destruction or deactivation of land mines. Computer modeling was used extensively to calculate and predict mine initiation. In order to facilitate comparisons between modeling predictions and experimental data, mine analogs were made. These analogs were intended to represent actual mines in their sensitivity to initiation by explosive countermeasures. In reality, the analog mines were found to be somewhat more sensitive than had been predicted by computer modeling, and thus might not accurately represent the M15 mine.</p> <p>In order to determine the reasons for this discrepancy in sensitivity, four analog mines and one M15 mine were sawed open and their contents analyzed. It was found that there are definite physical differences between the analog mines and the M15 which could account for this sensitivity difference. These differences are metal thickness, void structure, interfacial voids, and variations in RDX/TNT/Wax distributions. All of these variations except void structure were in the direction of causing an increase in sensitivity of the analog mines as compared with that of the M15 mine. <i>Keywords: Mathematical models; Detonations/sensitivity; Analog simulation; Explosives initiators.</i></p> | | | | |
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1. INTRODUCTION

Land mines are a very serious threat to Army operations. The task of which this study was a part involves the explosive destruction or deactivation of land mines. Computer modeling had been used extensively to calculate and predict mine initiation. In order to facilitate comparisons between modeling predictions and experimental data, mine analogs were made. They were intended to be used in comparison with computer modeling predictions of mine behavior when exposed to explosive mine countermeasures. These analogs were also intended to represent actual mines in their sensitivity to initiation by explosive countermeasures. In reality, the analog mines were found to be somewhat more sensitive than had been predicted by computer modeling, and more sensitive than the M15 mine.

In order to determine the reasons for this discrepancy in sensitivity, four analog mines and one M15 mine were sawed open and their contents analyzed. It was found that there are definite physical differences between the analog mines and the M15 which could account for this sensitivity difference. These differences are metal thickness, void structure, interfacial voids, and variations in RDX/TNT/Wax distributions. All of these variations except void structure were in the direction of causing an increase in sensitivity of the analog mines as compared with that of the M15 mine.

2. PROCEDURE

On 8 May 1990, one M15 mine and four analog mines were sawed open along specifically chosen planes in order to facilitate the study of factors which might cause increased sensitivity to initiation. The void structure, bonding of the explosive to the mine casing, and ratios of RDX:TNT:Wax as a function of position within the explosive were the factors that were considered pertinent. All of the mines, analogs and M15, were filled with Comp B explosive.

Figure 1 shows the apparatus used for sawing the mines. It is a large, mobile, electrically-powered bandsaw, with a water-cooled blade. As can be seen from the picture, this operation was carried out in the field, at a remote location. The operators controlled the operation from within a bombproof shelter. Figures 2 and 3 show an analog mine on the saw table, before and after sectioning, respectively. This and one other analog mine had been cast by the GOEX Company for the Waterways Experiment Station. The other two analog mines that were sectioned were made by the Ballistic Research Laboratory (BRL).

The process of cutting these mines left a residue, visible as the dark smudges on the cut surface of the mine shown in Figure 3. After the surface had dried, these residues were easily removed. A significant void is clearly visible in the photograph, several sawblade widths from the blade.

Figures 4 and 5 show the M15 mine in the process of being prepared for sectioning. The hand crank being operated in Figure 5 was used to secure the mines to the saw table during the sawing operation. Only light clamping force was used, so as to avoid debonding of the explosive from the mine casing.

3. RESULTS

3.1 Mine Casing Differences. Figures 6a and 6b are engineering drawings of the analog mine. It is basically a 3-in x 6-in x 8-in rectangular metal box. Minor variations in this design were made at times during the course of this program.

In the design of the analog mines, the thickness of the steel was chosen to conform to that specified for the M15 mine, viz., 20 gauge steel. This has a thickness of 0.032 - 0.035 in. In fact, the M15 mine which was sectioned in this experiment, has a steel casing with a thickness of 0.040 - 0.044 in, the exact value depending upon where the measurement was taken. This is likely a significant factor in establishing the sensitivity of these mines to explosive countermeasures and would decrease the M15 sensitivity as compared with that of the analog mines.

That there might be significant differences in the mine casing materials was first indicated during the sawing operation. The saw had routinely been cutting through the analog mines, along the 8-in dimension, in approximately 10 minutes. With the same settings, the saw blade would not cut the M15 mine. The lever arm on the counterweight had to be increased to compensate for the increased difficulty in sawing the M15 as compared with the analog mines. Initially it was thought that this behavior would be caused by differences in the hardness of the metals, but that proved to be false. The reason for this behavior has not been determined.

Hardness measurements were taken on the analog mine casings and on the M15. These measurements were made with a Shore Convoloader Hardness Tester. Before each set of measurements, the instrument was calibrated with the appropriate calibration sample supplied. The data are as follows in Table 1:

Table 1. Hardness Measurements

| Mine Type | Scale | | |
|-----------|--------|--------|--------|
| | Type D | Type A | Type O |
| M15 | 34 | 95 | 95 |
| Analog | 35 | 96 | 94 |

As can be seen from these data, the hardnesses of the mine casings are almost identical, so this parameter can safely be removed from consideration in trying to resolve the sensitivity discrepancy. The difference in ease of sawing was likely due only to thickness differences.

3.2 X-rays and Sections. In all cases, the planes along which the mines were sectioned were chosen from observations of their x-ray images. Copies of these, indicating these planes with dashed lines, are included in this report as Figures 7 - 11. The selections were made so that as many imperfections as possible would be revealed by the sectioning. Figures 7 - 10 are x-rays of the analog mines. The void structure is very apparent in these images. In Figure 11, the x-ray of the M15 mine, the void structure is not nearly as visible, but it is very clearly displayed in the photos made after sectioning. The M15 mine had many large voids, the largest being just inside the fill port, and many smaller voids throughout the explosive. Some of these were found by two cuts which were made transverse to the principal section, and others were deduced from the x-ray image.

Figure 12 shows the principal section of the M15 mine. Both surfaces of the section are shown here, almost as mirror images. The large voids mentioned above, just inside the fill port, are clearly visible. A transverse cut was made into the upper void, dramatically revealing its size and structure (see Figures 13 and 14). It can be seen that this void extends most of the distance across this side of the mine, just adjacent to the fill port. This type of void structure is probably characteristic of these mines because of the way in which they are likely filled, i.e., stood on edge

with the fill port up, filled by casting, capped, and allowed to cool. As the explosive shrinks, the voids form.

The analog mines also had voids, but they were much smaller than the dominant voids in the M15 mine. There was little difference in the number and size distribution of the voids within the set of these four analog mines. One of the mines had been cast with two pours; this resulted in some voids at the interface between the two pours. This mine is shown sectioned in Figure 15. The more usual void structure is that shown in Figure 16, a clustering of voids near the top. These voids can be corrected by probing with a steam finger, melting and filling them.

No special care had been exercised in the casting of these analog mines. Earlier in this program, "perfect" mines were made. Special care was taken in the initial casting; the mines were x-rayed, and the steam finger was used to probe and repair the defects. This was a labor-intensive operation and thus was not used in the production of the mines described here.

3.3 Discoloration. Discoloration of the explosive was not anticipated but may provide a clue to the difference in sensitivity between the M15 and the analog mines. In the production of the analog mines, an oil-in-water emulsion was used as a rust preventative. This material was found to be mildly incompatible with the explosive, so before filling the mine casings, they were washed with acetone. Some of the emulsion must have remained after the washing because there is a discoloration evident in the analog mines, particularly near the corners (see Figure 16). A Pittsburgh Lock Seam was used in the manufacture of the mine casings. This is a somewhat complex structure and so was likely able to trap the emulsion in the corners. There is currently no evidence as to whether this has an effect on the sensitivity of the mines. Most mines were fired soon after fabrication, so the chemical reaction indicated by the discoloration would not have had much time in which to operate, to either sensitize or desensitize the explosive.

The surfaces of most of the voids in the M15 mine also showed discoloration, being somewhat darker in color than the bulk explosive. Figure 13 shows this clearly. TNT has approximately 12% shrinkage from the molten to the solid state and with inadequate risers will cause the observed voids within the bulk material. The surfaces of these voids are likely the last of the explosive to solidify. As the explosive solidifies, the interface between solid and liquid will contain whatever impurities that the crystalline material cannot readily accept. The final interface is the surface of the voids, which becomes the repository of the impurities. These impurities could cause the explosive to crystallize differently from the bulk of the explosive, so this deviant structure with

impurities may be the cause of the discoloration. There is no evidence that this discoloration has any effect upon the sensitivity of the M15 mines.

Discoloration was also observed along the saw cut in the M15 mine. This appears to have been an artifact of the sawing process because some of these stains were only on the surface. Removal of the surface layer restored the natural color of the Comp B explosive.

3.4 Interfacial Voids. The interface between the explosive and the mine casings was also investigated. Neither liner material nor bonding agent was used in the fabrication of the analog mines, nor apparently in the manufacture of the M15 mines. In all cases, there was no affinity between the explosive and the mine casings. Figure 17 is another view of the analog mine shown in Figure 15, this time with a knife blade inserted between the explosive and the mine casing. This was easily done because there was no bond between the two. However, neither did there appear to be significant void space at these interfaces; the explosive filled the casings (except for the voids). It may be possible, since there was no bonding and the metal was thin, that a small gap could exist in the broad faces of the analog mines and that a shock enhancement could take place.

Ms. Kelly Benjamin of BRL has recently modeled the sensitivity of the analog mines with and without a small air gap between the mine casing and the explosive fill. The code that was used was 2DE, a two-dimensional Eulerian hydrocode. The model parameters were: 2-mm-thick Detasheet explosive in intimate contact with the broad surface of the analog mine; mine casing thickness, 0.036 in (0.91 mm); and air gap of half the casing thickness. The observable parameter was the time to detonation. The reaction proceeded to detonation at 10.5 and 12.0 μ sec, with and without the air gap, respectively. This is about a 14% difference, with the air gap causing sensitization.

3.5 Component Distribution. The distribution of RDX/TNT/Wax in the Comp B fill of the analog mines and the M15 was also investigated. Samples were taken 1 cm, 10 cm, and 19 cm from the base of the analog mines, along the center plane, and midway between the broad faces. A sample was taken in the middle of the principal saw cut on the M15 mine and at the orthogonal cuts near the top and bottom of the mine in the fill position, i.e., with its fill port at the top of the mine. In its normal position, resting on its broad face, the fill port of the M15 mine is located on the side, in the curved surface. See Figure 14. The data are as follows in Table 2:

Table 2. Composition Analysis of the Explosive Fill of the Analog and M15 Mines

| Mine | Sample | % RDX | % Wax |
|------------|-----------------|-------|-------|
| Analog #1 | 1 cm From Base | 65.8 | 1.1 |
| | 10 cm From Base | 61.5 | 0.5 |
| | 19 cm From Base | 51.1 | 1.2 |
| Analog #2 | 1 cm From Base | 64.6 | 1.0 |
| | 10 cm From Base | 70.1 | 1.3 |
| | 19 cm From Base | 66.1 | 1.8 |
| Analog #9 | 1 cm From Base | 62.4 | 1.0 |
| | 10 cm From Base | 64.5 | 0.5 |
| | 19 cm From Base | 61.3 | 2.5 |
| Analog #10 | 1 cm From Base | 66.7 | 2.0 |
| | 10 cm From Base | 64.6 | --- |
| | 19 cm From Base | 60.1 | 4.1 |
| M15 | Top | 45.9 | 3.2 |
| | Middle | 59.7 | 4.1 |
| | Bottom | 60.6 | 2.1 |

Notes: Each number is the average of three determinations.

All samples are composed of RDX, TNT, and wax, the quantities totalling 100% for each sample.

Analog mines #1 and #10 and the M15 mine show the expected RDX distribution, i.e., a concentration gradient from top to bottom, with the greatest concentration at the bottom. Analogs #2 and #10 show the expected wax distribution, i.e., a concentration gradient from bottom to top, with the greatest concentration at the top. However, the other data indicate that these may be random coincidences because these data are quite scattered.

Two features do stand out from these data: the very low concentration of RDX near the fill port, and the relatively large amount of wax in the M15 mine. When the M15 mine was tested for sensitivity to initiation by foam explosive, only part of the mine was covered by the explosive. If that part contained the low concentration of RDX, and if this RDX distribution is consistent for the M15 family of mines, then one would expect to observe lower sensitivity. Similarly, since the wax content of the M15 explosive fill is considerably greater than that of the analog mines on the average, this should lead to reduced sensitivity.

4. DISCUSSION

From the above, it can be seen that there definitely are physical parameters that are likely to cause a difference in sensitivity between the M15 mine and the analog mines. These are: metal thickness, void structure, interfacial voids, and the variations in RDX/TNT/wax distributions. All of these variations except void structure were in the direction of causing an increase in sensitivity of the analog mines as compared with that of the M15 mine. The void structure for the M15 and analog mines was similar except that the M15 also had some very large voids. The effect of these large voids, in addition to the smaller voids, on initiation sensitivity has not been determined. Discoloration may be a factor, but there is no evidence to establish that.

From these experiments, it can be seen that the term "analog," referring to these surrogate mines, cannot be taken too seriously. They could still be used in many experiments, but conclusions drawn from these tests cannot be applied directly to the expected behavior of M15 or other mines. The analog mines appear to be quite uniform and consistent in most of the important parameters, and can therefore legitimately be used to compare modeling with experiment and can be used as a basis for honing the analytical models. This is especially true for analog mines with which special care was taken in their manufacture, e. g., vacuum casting and steam finger repair of voids. The problem arises in trying to apply the results of these studies to real mines since at least the M15 appears to be a very crudely, and likely inconsistently, manufactured device.

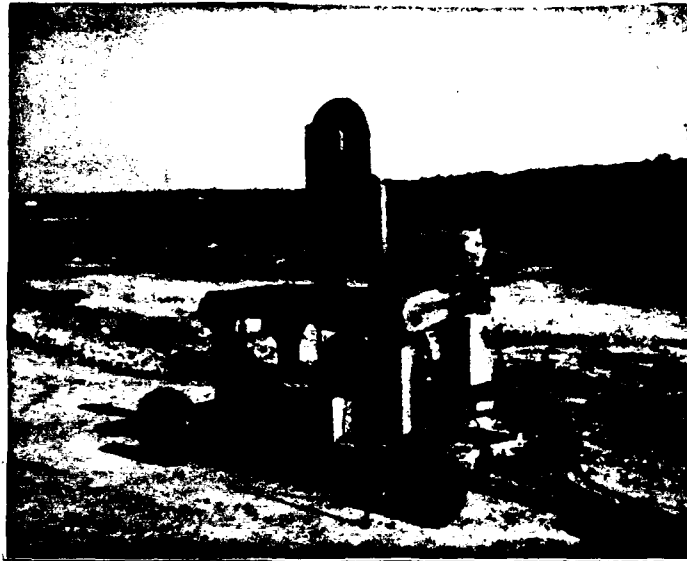


Figure 1. Field Saw for Cutting Mines.



Figure 2. Analog Mine. Ready for Cutting.

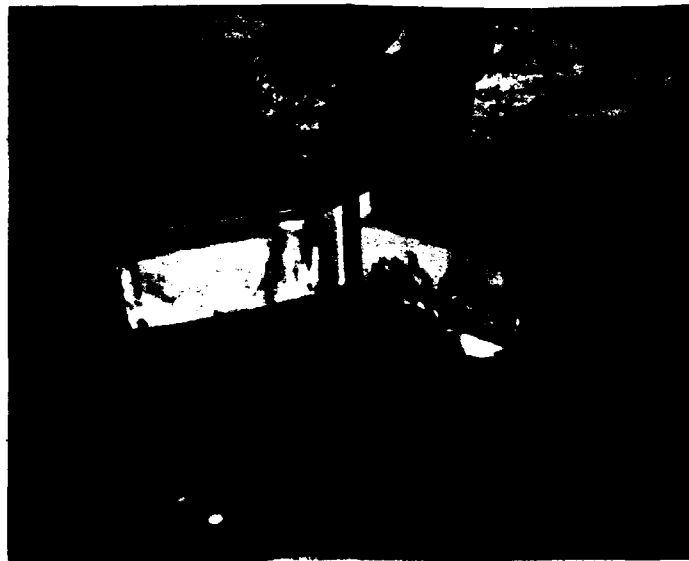


Figure 3. #10 GOEX Analog Mine. Just After Cutting.



Figure 4. M15 Mine. Ready for Cutting.



Figure 5. M15 Mine. Ready for Cutting.

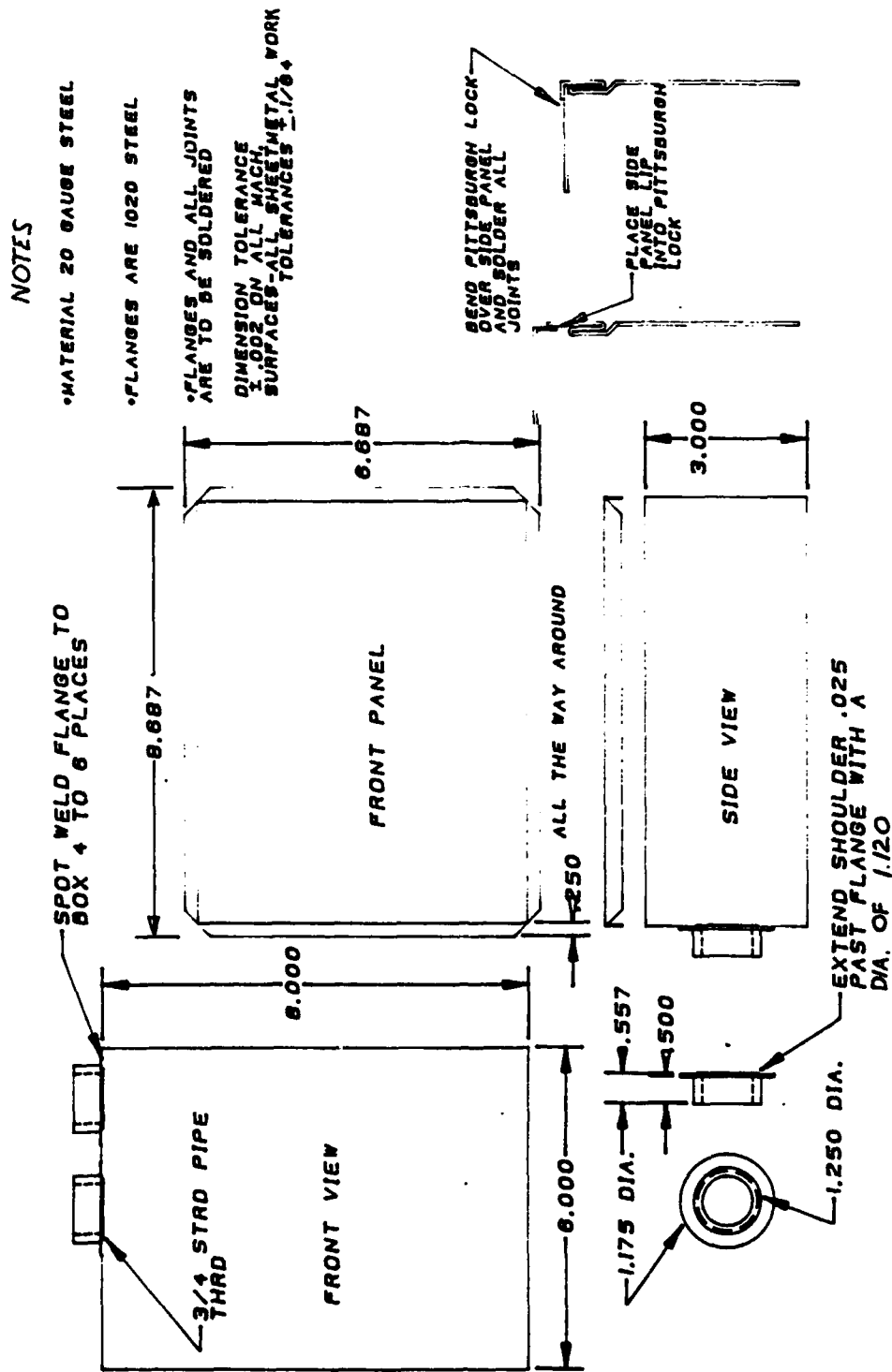


Figure 6a. Engineering Design of Analog Mine.

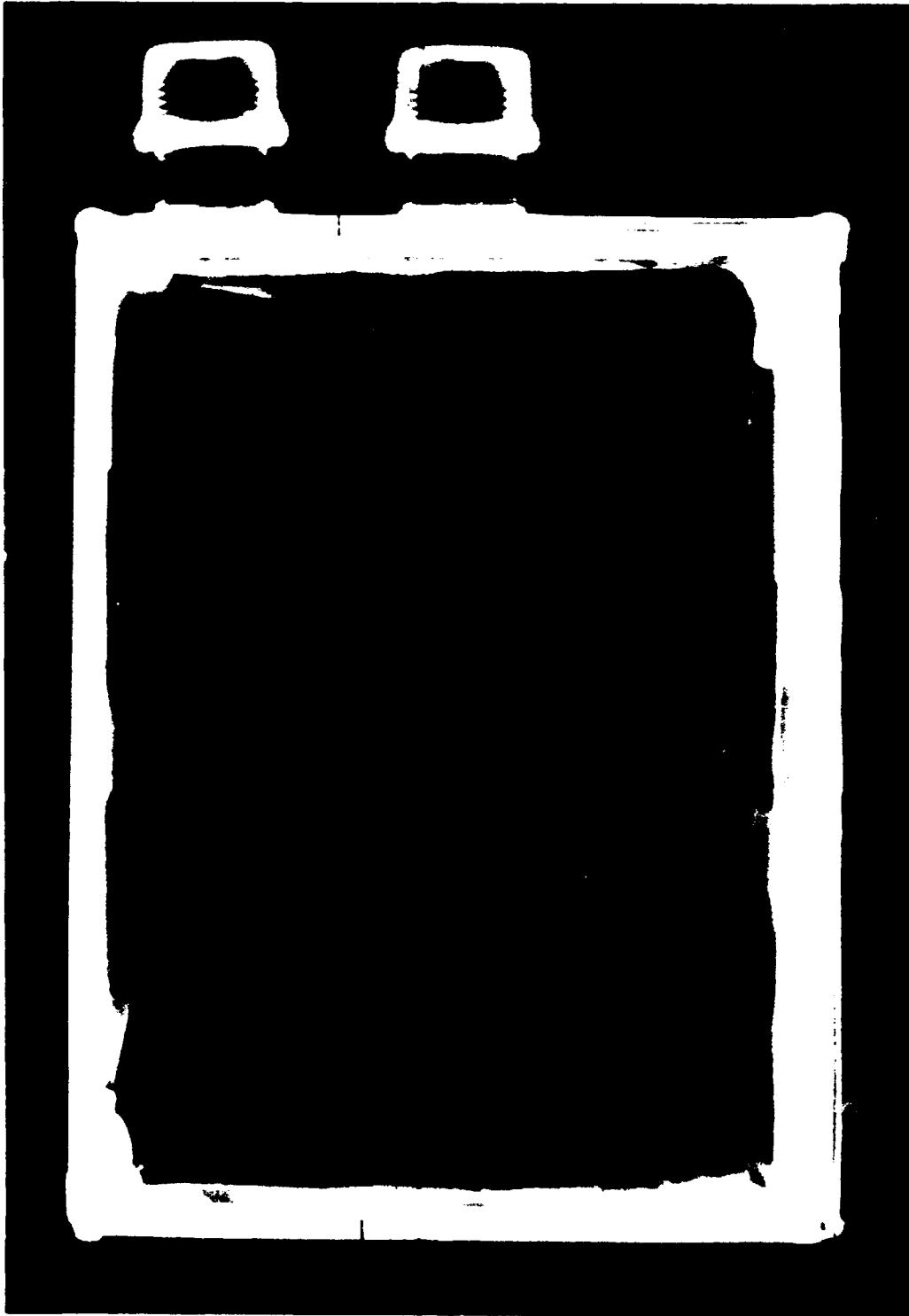


Figure 7. X-ray of Comp B-Filled Analog Mine #1.

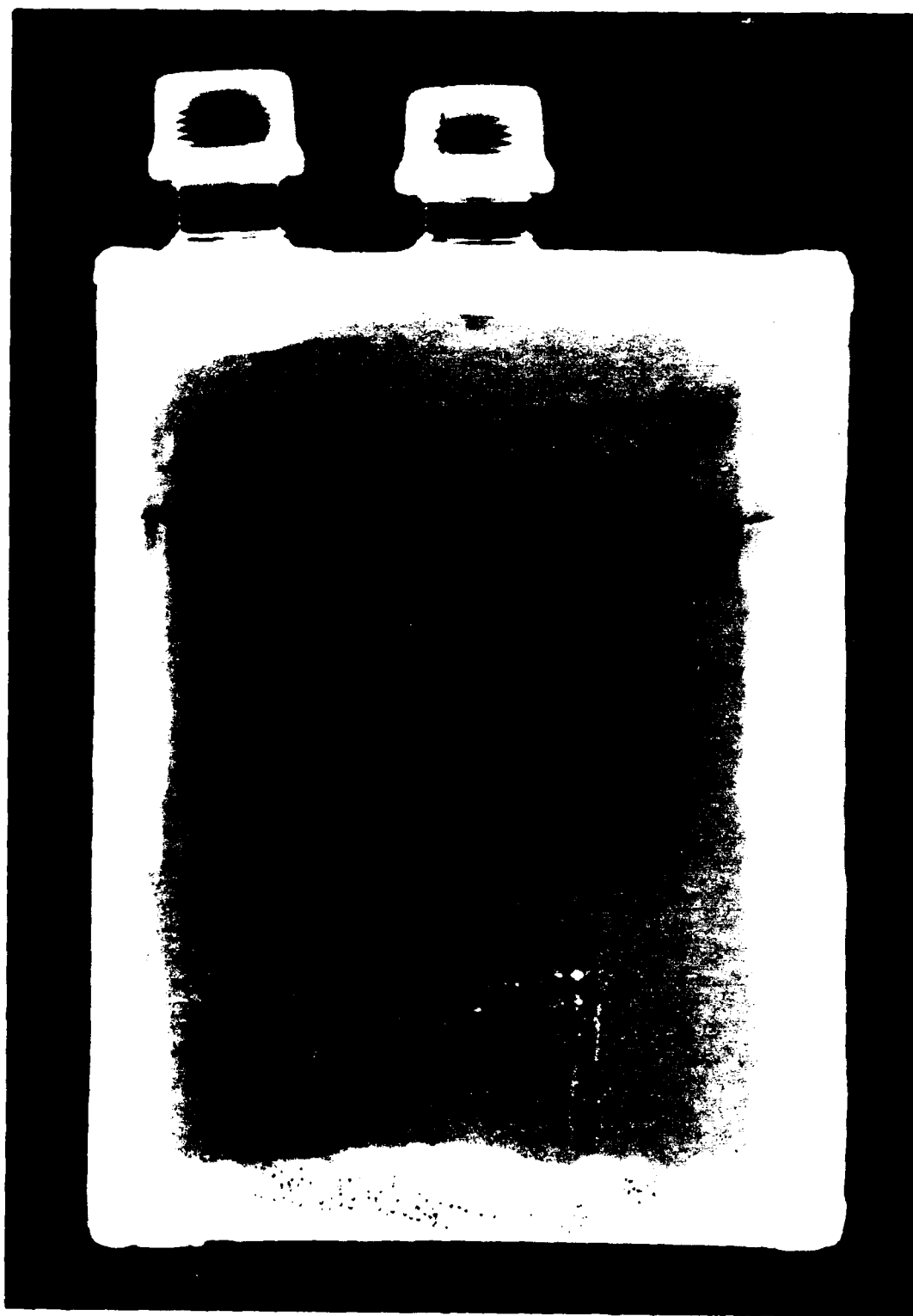


Figure 8. X-ray of Comp B-Filled Analog Mine #2.

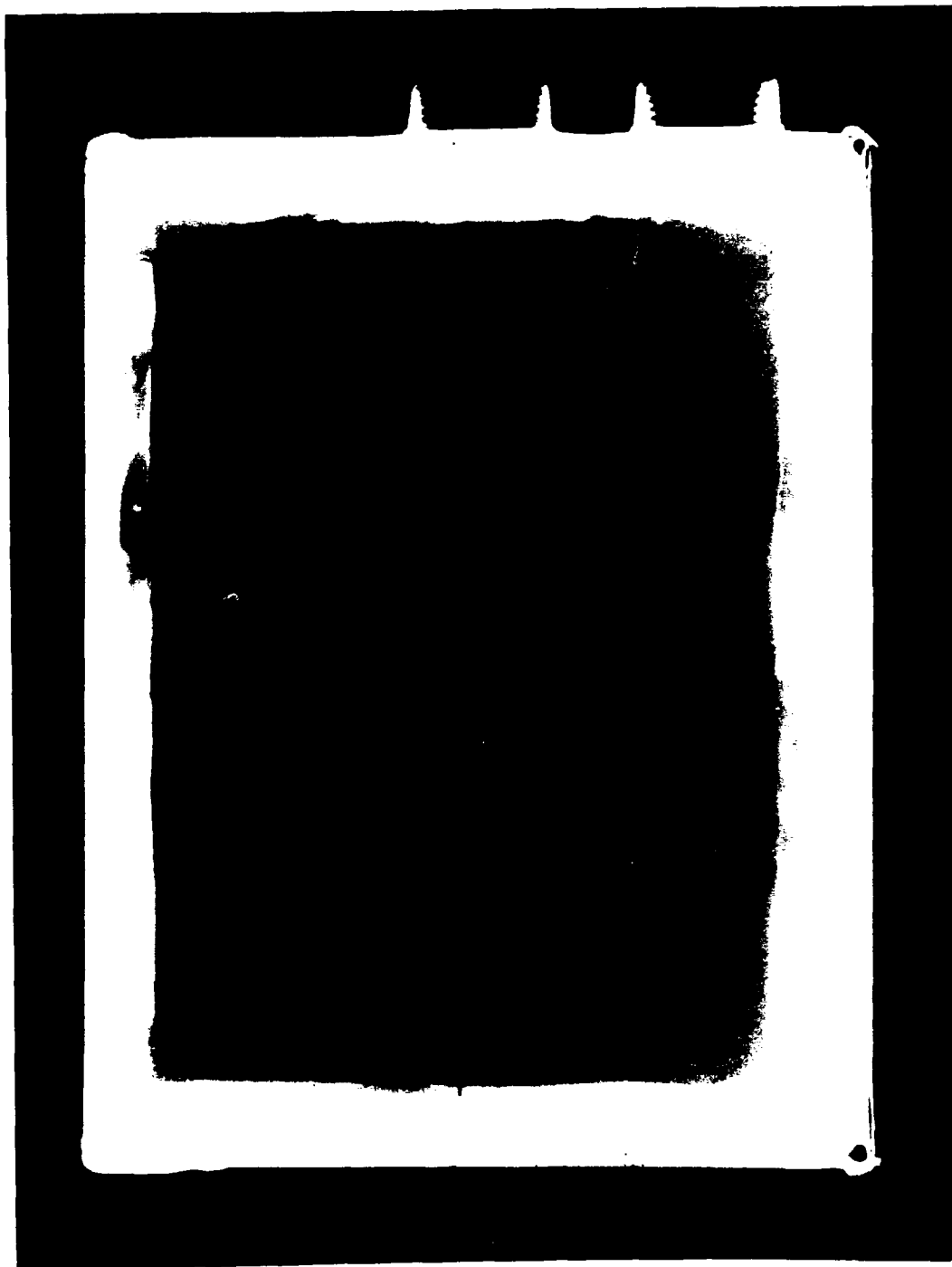


Figure 9. X-ray of Comp B-Filled Analog Mine #9.

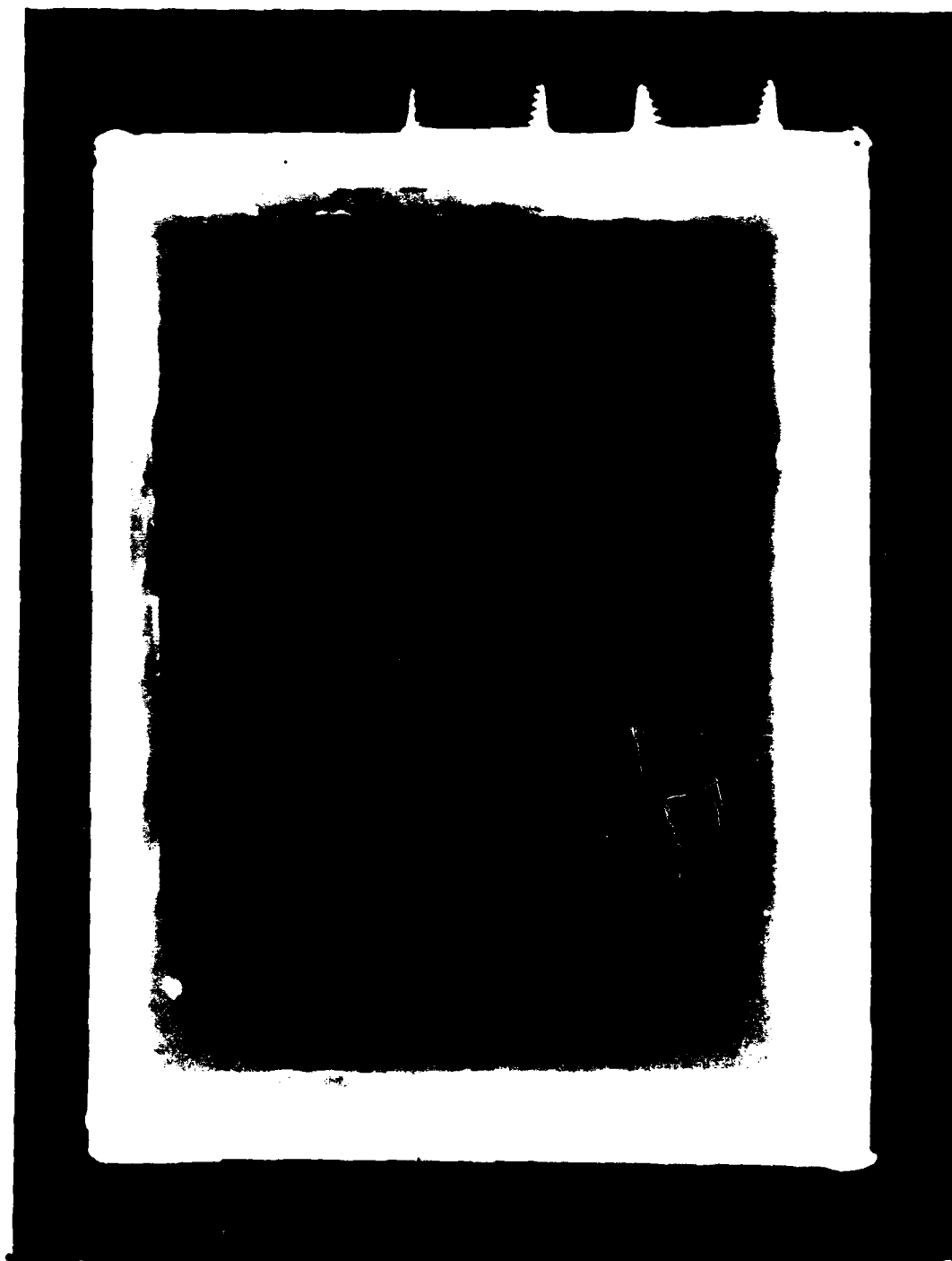


Figure 10. X-ray of Comp B-Filled Analog Mine #10.

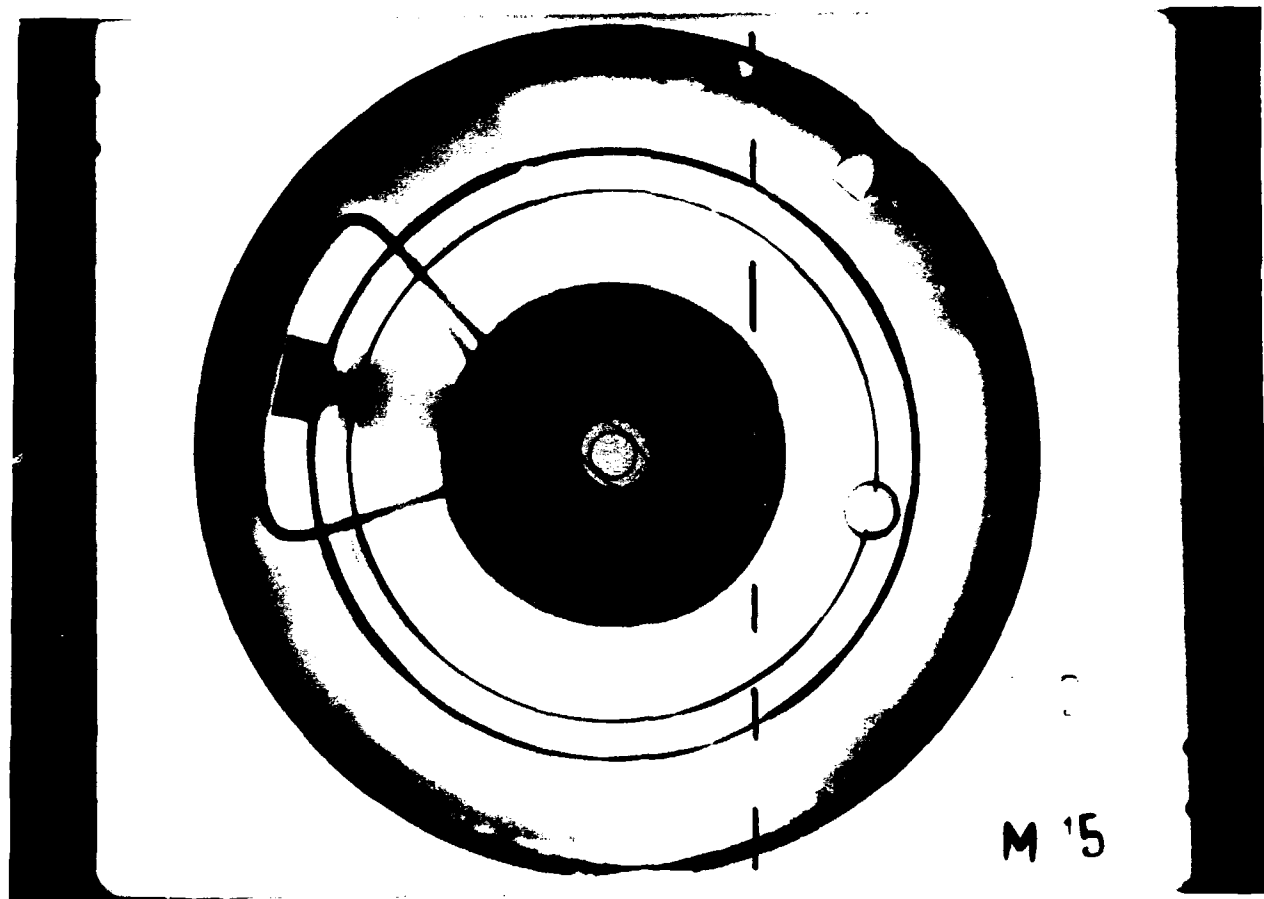


Figure 11. X-ray of M15 Mine.

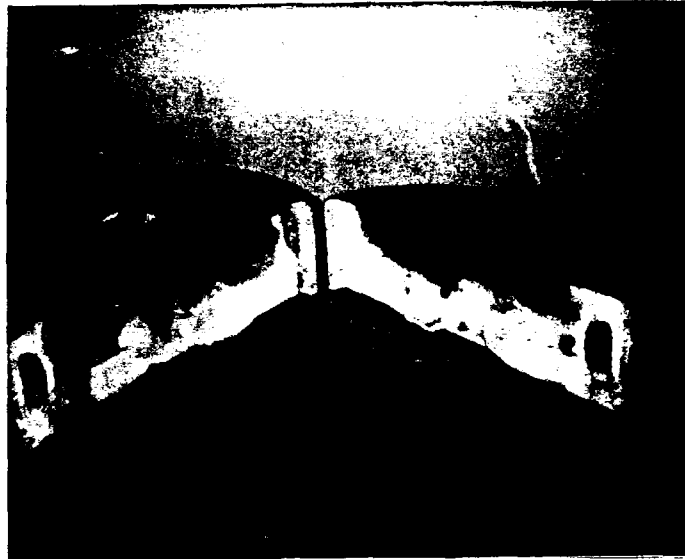


Figure 12. Principal Section of M15 Mine.

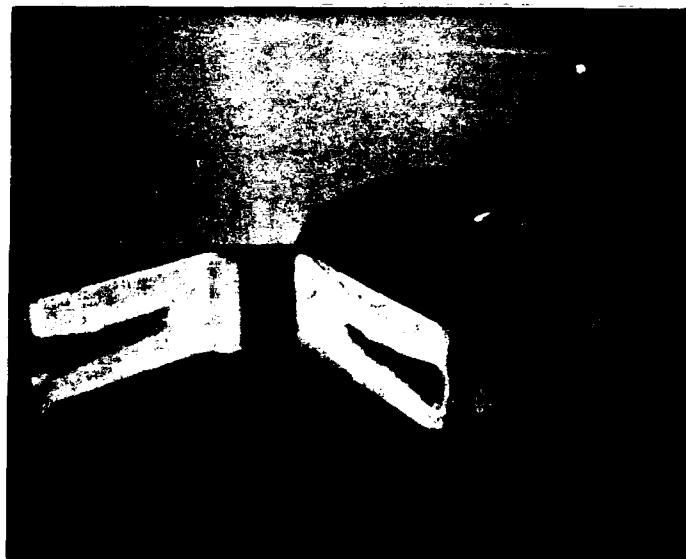


Figure 13. M15 Mine. Traverse Cut in Upper Void.

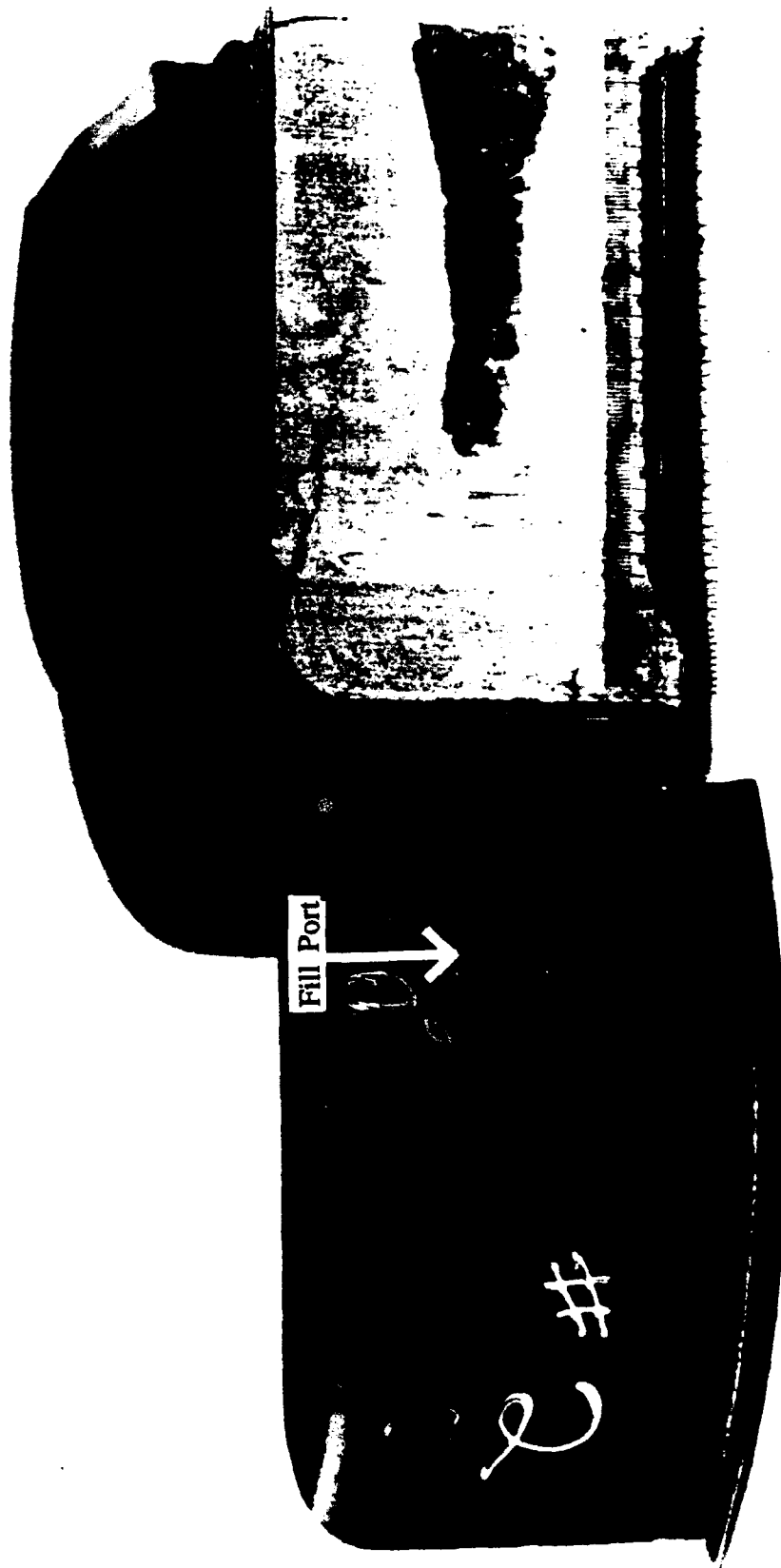


Figure 14. M15 Mine. Traverse Cut in Upper Void.



Figure 15. Analog Mine No. 2.

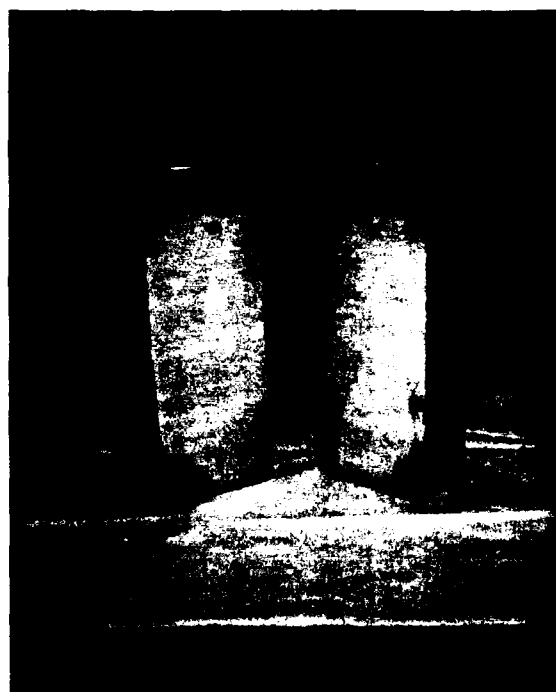


Figure 16. Analog Mine No. 1.

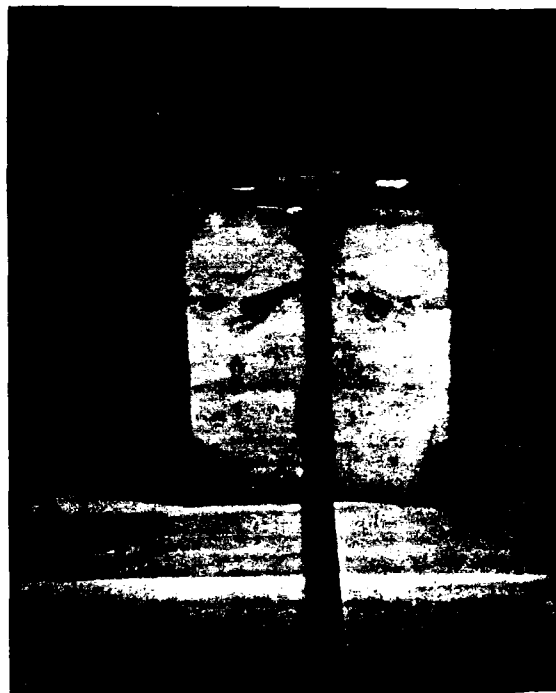


Figure 17. Analog Mine No. 2. Debonding.

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